A Virtual Reality Based Gas Assessment Application for Training Gas Engineers

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ABSTRACT

Once a gas leak is reported, the rescue operation usually requires safe and precise identification of a leak source and stopping it. However, it is risky to train new gas engineers in a real gas leak situation. This paper aims to address this challenge by proposing a virtual reality (VR) based Gas Assessments and Training (GAT) Application (App) that helps gas engineers gain practical experience on correct gas safety procedures. The GAT App also trains them to make prompt decisions and practice relevant safety measures for a real gas leak situation. User testing was performed with 16 gas engineers. They have gone through different tasks and filled System Usability Scale (SUS) questionnaires. Data analysis revealed a SUS score of 84.06, which indicates that participants enjoyed using the GAT App and will recommend it to their colleagues. However, there is a need for more user testing for result generalisation.

CCS Concepts

• **Human-centred computing → Interaction paradigms→ Virtual reality** • **Human-centered computing → Human-computer interaction (HCI) → Usability testing.**

Keywords

Gas Assessments; Virtual Reality; Training; Safety; Usability; Questionnaire.

1. INTRODUCTION

The improper installation and maintenance of gas appliances such as boilers, ovens, and cookers can cause carbon monoxide (CO) poisoning, gas leaks, or even explosion. Additionally, a gas leak in a confined space with occupants can cause numerous challenges in rescue situations due to ventilation problems, fire risk, and lack of evacuation routes. According to the Carbon Monoxide and gas Safety Society, there have been 697 deaths in the UK between 1995 and 2018 caused by CO poisoning. Also, there have been 5541 near misses from CO poisoning in the UK during the same period. Among these statistics, more than 2350 required hospital treatment and over 450 lost consciousness [1].

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Gas engineers are the first point of call when reporting a gas leak. Hence, it is imperative that they receive the appropriate training to minimise the potential risks to life and property. The training of individual gas engineers on a full-scale real-life gas leak incident, and incorporating all possible variants of the cause of the leak will come at a high cost (time and financial), and present a potential risk to life. This approach will require the building of dedicated infrastructure that enable trainees to utilise their learnt skills practically.

As a potential solution, incorporating a technological solution such as Virtual Reality (VR) in the training process of gas engineers will help mitigate the financial burden and time constraints with zero risks to life. VR provides an interactive approach to learning; it has the potential of increasing the user's engagement, which in turns improves their knowledge retention over time. Research around this area indicates that increasing trainees interactions during learning can increase their achievement and knowledge retention [2].

This paper proposed a Gas Assessments and Training (GAT) Application (App) for training gas engineers. The GAT App can be an addition to the current training modules for gas engineers. The GAT App aims to provide an avenue for gas engineers to practice their learnt skills on a recreation of a realistic gas leak incident in a virtual environment. Gas engineers can practice on real-life gas incidents and learn from past fatal incidents. The proposed VR-based App consists of two scenarios. The instructions on how the trainee gas engineer can explore the VR environment is provided. The App evaluates how well gas engineers can identify appliances that are more susceptible to a gas leak in a residential home. The engineer's reaction time and knowledge base when dealing with a gas incident are also evaluated. The first scenario focused on the identification of hazardous appliances (those susceptible to a gas leak) and the second scenario focused on testing the reaction time of the gas engineer when dealing with a gas leak. Sixteen gas engineers evaluated the GAT App; they completed the System Usability Scale (SUS) questionnaires after using the GAT App. The overall results suggest a positive outcome on the ease of use of the GAT App by the gas engineers.

This paper contains five sections. Section 2 includes related work to this study. Section 3 describes the research methodology. Section 4 contains the results and discussion. Finally, the conclusion and future work are in Section 5.

2. RELATED WORK

This section presents the literature relevant to the current study. VR has been in existence for over 50 years; however, it gained much importance in the last decade due to recent advancements in technology. The following examples highlight how different sectors have benefited from VR.

Paper [3], developed a VR based fire-training simulator for the general public and inexperienced firefighters to practice how to react in a fire incident in a tunnel. The study developed a realistic fire scenario in VR using Computational Fluid Dynamics (CFD) to predict the actual fluid behaviour. Firefighters evaluated the system, and they liked the idea. However, the firefighters suggested more can be done to make the design more realistic [3].

Smoke is the leading cause of death when there is a fire incident. Hence, a VR based smoke hazard system was developed by the paper [4]. The VR system visualisation technique used fire dynamics data and volume rendering to make the scenario closer to reality. The author presented two case studies: a primary school and a subway station. The firefighter has to choose the right path to evacuate the victims trapped in a fire. The training helped the firefighters to identify a safe path with minimum smoke hazards.

Paper [5] developed a VR application to investigate people's behaviour during a tunnel fire evacuation and to understand their evacuation paths. The study simulated a tunnel with a fire emergency and evaluated the App with 21 participants. About 15 of the participants made it to the emergency exit; 5 of the participants made it to the emergency phone while one made it to the tunnel entrance safely. The experience of the participants was recorded via a questionnaire. The results showed that participants do not always use the shortest path to reach the exit.

Authors such as [6], explored the effect of a 'burning dangerous goods transporter' on occupants hazard perception in a tunnel. The experiment consisted of two groups; the first group were exposed to burning gasoline transporter, while the controlled group were exposed to a heavy-duty burning transporter in VR. The participants in the experiment group rated the hazard from the 'burning dangerous goods transported' higher than that from the heavy goods transporter. The experiment showed that proper evacuation signs are helpful for quick and safe fire evacuation in a tunnel [6]. In another interesting work, the researchers designed a VR-based emergency rescue training system for railway cranes operators. A visualisation framework based on PhysX engine was designed to reconstruct a realistic railway accident. The user testing involved 10 crane operators who carried out a rescue mission in a VR environment. The system was evaluated using questionnaires and interviews. The results showed that the proposed system was considered easy to use, interactive and intuitive [7].

In a chemical process industry, a VR and Augmented Reality (AR) based training system was used to improve the readiness of employee's in handling risky incidents. The study considered three areas of employee's awareness: experiencing risky situations, comprehending the risks and learning to deal with emergencies. The study outcomes include an increased awareness in employee's response in a risky situation [8].

Moreso, the aerospace industry has experimented with ViRstperson VR engine to train their trainees through the combination of VR and haptic interaction. The system was tested on eight technicians. The testers have to complete eight different tasks containing 20 to 37 operative steps. The usability of the system was evaluated using a questionnaire. The results were encouraging as participants appreciated the VR accuracy, visual realism and efficacy [9].

VR is equally beneficial for training miners, as mining can be risky. The author [10], developed a VR application called MineVR. The application reconstructed mining incidents to train employees in the mining industry [10].

A VR app was developed to train schoolchildren on safety procedures in railway level crossing. The user testing revealed that the children were more engaged throughout the sessions, and they enjoyed the VR experience [11].

Additionally, VR has been used as a training tool in car maintenance, surgical operations, teaching activities and related fields [12]. However, there is a lack of VR based training applications for gas engineers. This study adopts a co-design approach in the development, implementation of a VR based GAT App for training gas engineers.

3. RESEARCH METHODOLOGY

This section contains the research process and the relevant material for this study. These include details of the participants involved in the evaluation, an overview of the GAT App, questionnaires and data collection procedures.

3.1 Participants

The participants for this study consist of expert gas safety inspectors from the industry. There were 16 participants (10 Male and 6 Female) in total with age ranging from 25 - 62 years old. A summary of the participants demographic is shown in table 1. The mean age of the participants is 45.94, with a Standard Deviation (SD) of 12.94. The participants were separated into two groups based on their age. The first group consists of participants that are aged (<=40) years old while the second group consists of participants (>40) years old. Six participants were in the first group, while ten were in the second group.

Table 1. Demographic Information of Survey Participants

Gender	Female	6	38%
	Male	10	62%
Age	<= 40	6	38%
	> 40	10	62%

3.2 Overview of the Gas Assessments and Training Application (GAT App)

The GAT App was created via a process of co-design [13], where researchers collaborated with experts from the gas industry with over 20 years of experience. The GAT App contains two scenarios. In the first scenario, the trainees are required to explore a typical residential home in a virtual space and identify potential hazards (CO or gas-emitting appliances). The trainees start the scenario from outside the property, as shown in Figure 1. They can navigate the scene by teleporting with the aid of a controller. They can also carry out specific tasks (open/close doors, taking appliance reading and marking an appliance as a hazard) in the VR space by pointing the controller in the direction of the appliance or door. This will bring up a set of options: Appliances - *Take reading or Mark as a hazard*, Doors - *open/close*. A screenshot of inside the house and the selection menu is shown in figure 2 and figure 3, respectively. Once the trainees finish the scenario, they can view their results and see if the appliances marked are correct, and if they have missed any.

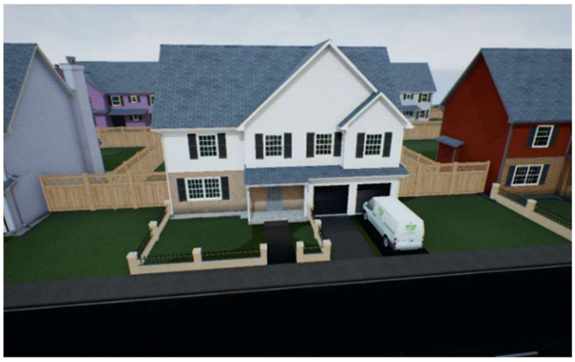

Figure 1. Outside the VR Residential Home

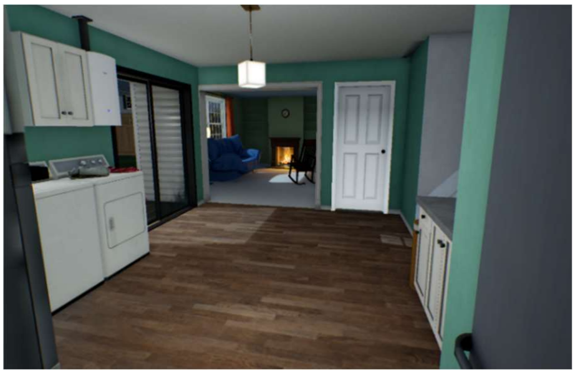

Figure 2. Inside VR Residential Home

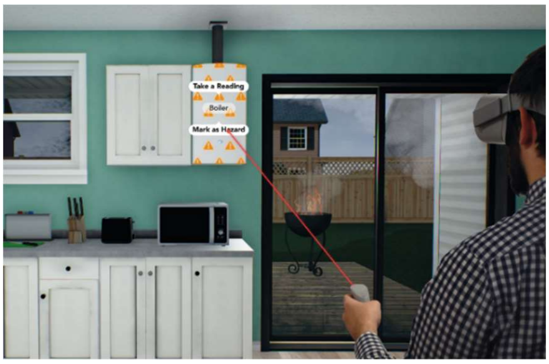

Figure 3. Possible Actions – First Scenario

The second scenario involves the trainee following a storyboard of a gas leak event that could potentially occur in a real household. They must follow the correct protocol and procedures to safely inspect the situation and solve the problem within 40 seconds. A screenshot of possible actions available to the trainees when investigating the source of a gas leak is shown in Figure 4. The trainees can take the reading of the appliance, mark it as hazardous or disconnect the appliance. Making mistakes and not finding the source of the gas leak within the stipulated period can have catastrophic consequences (such as explosions) in the VR space. These two scenario aims to aid the training of gas engineers; hence, it should be an addition to the current training program.

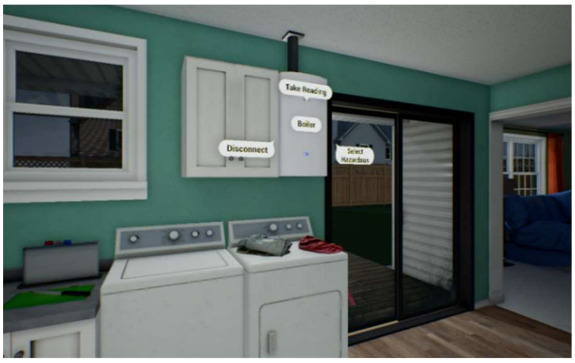

Figure 4. Possible Actions – Second Scenario

3.2.1 Design of GAT

The GAT App is developed using Unreal Engine 4 (UE4). It uses the Oculus Go as an affordable standalone headset that requires minimal setup and uses 3-Degrees of Freedom (3DoF) controller. This means it has tracked in rotation forward/backwards, left/right and up/down. A pointer was used for User Interface (UI), which is used to select objects and interact with a menu to perform actions within the scenario. Due to the resolution of the headset and scale of the 3DoF controller, representing any icons on the controller would be very small, especially because the 3DoF controller cannot be brought closer to the headset. Therefore, a tutorial was added at the start. Context-appropriate interactions performed the Level navigation, i.e. go through a door to enter a level and exit scenario by getting in the gas assessments company van etc. This helped with immersion, as the VR experience is more realistic, navigating a full-screen menu in VR is not ideal as it takes the user away from the immersive scenario.

3.3 Questionnaire and Data Collection

The GAT app was evaluated using the System Usability Scale (SUS) questionnaire [14]. Over the past 30 years, the SUS questionnaire has been popularly used in different sectors to evaluate system usability. Hence, thousands of studies have used the questionnaire, which is proof of its reliability as an instrument for measuring system usability [15]. The SUS is considered a specialist usability tool in case of smaller sample size. The lowest sample size required when using a SUS questionnaire is five [16]; hence, the sample size of 16 used for this study is acceptable.

The SUS questionnaire is based on the following questions:

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

The testing of the GAT App continued over multiple sessions. At the start of each session, the participants were briefed about the GAT App, its functionalities, and how to navigate the VR environment. All the participants signed consent forms before taking part in the testing. A senior gas assessments engineer was present during the entire testing process to help the participants in need of assistance. After completing both scenarios, the participants completed the SUS usability questionnaire.

4. RESULTS AND DISCUSSION

The result and discussion of the usability questionnaire for the 16 participants are discussed in this section. The standard SUS data analysis process is followed during data analysis and result interpretation [17].

4.1 SUS Data Analysis

The participants had the choice to select from five options; strongly disagree (1), disagree (2), neutral (3), agree (4) and strongly agree (5). SUS scores are calculated by standard SUS calculations, as explained below:

X = Sum of the points for all odd numbered questions – 5

Y = 25 – Sum of the points for all even numbered questions

SUS Score = (X + Y) x 2.5

The summary of the SUS scores for all the participants is shown in Table 2. Historically, the average SUS score is 68. A SUS score greater than average means the system usability is good. If the SUS score is below the average, there is a problem with the system usability [18]. As per Table 2, the SUS score for 14 of the 16 participants is 75 and above. The remaining two participants have a SUS score of 62.50 and below. The SUS score of 75 and above, means the 14 participants were satisfied with the system usability. However, the two participants with SUS score of 62.5 and below have a problem with the system usability.

Table 2. SUS Data Summary from the Testing Participants

Sr. No	Age	Gender	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	SUS Raw Score	SUS Final Score
1	31	Male	5	1	5	5	5	1	5	1	5	1	36	90.00
2	56	Male	5	1	5	3	5	1	4	1	5	1	37	92.50
3	25	Female	5	2	4	2	4	2	5	2	4	2	32	80.00
4	59	Male	5	2	4	2	5	1	4	1	4	2	34	85.00
5	58	Male	4	2	4	2	4	1	5	1	4	1	34	85.00
6	56	Male	1	5	4	2	3	2	4	2	3	2	22	55.00
7	60	Male	3	2	4	4	4	2	3	2	4	3	25	62.50
8	51	Male	4	2	4	2	4	2	4	2	4	2	30	75.00
9	37	Female	5	1	5	2	5	2	5	1	5	2	37	92.50
10	28	Female	5	1	5	2	5	2	5	1	5	2	37	92.50
11	50	Female	4	2	2	2	5	1	4	2	5	2	31	77.50
12	29	Female	5	1	4	1	5	1	5	1	4	1	38	95.00
13	34	Male	5	1	5	1	5	1	5	1	5	1	40	100.00
14	41	Male	5	1	5	2	5	1	5	1	4	1	38	95.00
15	62	Male	4	2	4	2	4	2	5	1	4	2	32	80.00
16	58	Female	4	2	5	1	4	1	4	2	5	1	35	87.50
												Average	**34**	**84.06**

The recommended grade level for SUS score and their descriptions are as follows: 80.3 or above is a Grade A, 68 or thereabout is a Grade C and Grade F for 51 and under [19].

Grade A – The participants enjoyed using the system, and they will recommend the system to their colleagues.

Grade C - The participants think the system is ok, but there is room for improvement.

Grade F - The participants think there is a significant usability flaw with the system. This flaw will have to be urgently addressed to improve system usability.

The average SUS score for all the participants using the GAT App is 84.06, as shown in Table 2. This indicates a SUS score in Grade A level, meaning they enjoyed using the GAT App and will recommend it to their colleagues.

4.2 SUS Scores for Demographics

The SUS score based on demographics is shown in table 3. According to table 3, the average SUS score for female and male are 87.50 and 82.00, respectively. There is no significant difference with the gender demographic as both SUS score for male and female are Grade A.

Table 3. SUS Scores for Demographics

Demographics	Group	SUS Final Score
Gender	Female	87.50
	Male	82.00
Age	<= 40	91.67
	> 40	79.50

The average SUS score for participants (<= 40) years old is 91.67 (Grade A), while that for participants (> 40) years old is 79.50 (Grade C). Based on this result, the participants aged 40 years old and below enjoyed using the system more as compared with those above 40 years old that think there is room for improvement of the GAT App. However, the SUS score for those above 40 years old is 0.4 lower than 80.3 (scores required for a Grade A). Hence, the difference in the SUS score is not as significant as the grade levels might suggest.

5. CONCLUSION AND FUTURE WORK

This paper proposed a GAT App that can be incorporated into the current training course for gas engineers. The GAT App provides an avenue for gas engineers to utilise their learnt skills practically. The VR space consists of two scenarios, the first of which requires the gas engineers to explore a residential home to identify and mark any appliance susceptible to potential CO or gas hazard. The second scenario requires gas engineers to follow the correct protocol and procedures to safely inspect a gas leak and solve the problem within 40 seconds.

The use of the GAT App will reduce the financial cost required to set up a realistic gas leak event, and the App will remove the potential risk to health or life that could arise when a trainee gets it wrong.

The GAT App was evaluated with the SUS questionnaire. The average SUS score for the 16 participants was 84.06, which is a Grade A level. Generally, the participants enjoyed using the GAT App and will recommend the App to their colleagues. There is no significant difference between the average SUS score for male and female demographic as both scores are Grade A. However, there is a slight difference in the SUS score for the age demographic. The participants aged 40 years and below had an average SUS score level of Grade A, while those over 40 years have a SUS score level of Grade C. These results are consistent with the literature [20].

Although the SUS results are promising for the GAT App, more user testing and more research on the long term impact of this application for training gas engineers are required to generalise these findings.

Some of the limitations of this study include the small sample size, limited gas leak scenario and the visualisation of the trainee's action in the VR space (there is no onscreen view for the instructors). Also, the scenario in the GAT App will have to be short, as excessive VR exposure can result in dizziness and sickness for the user [21]. Future work can explore multi-user training platform, which allows gas engineers to work in teams.

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